Thermal properties of matter

Important question and answers

Question (1): Derive relation between coefficient of linear expansion, areal expansion.

To derive the relationship between the linear expansion coefficient (α) and the areal expansion coefficient (β), let's consider a square material with a side length L. When this material is heated, it expands both in length and width.

1. **Original Area:** The original area of the square, A_0, is given by: $A_0 = L^2$

2. **Expanded Length:** Upon heating, each side of the square expands according to the linear expansion coefficient (α). If the temperature change is ΔT, the new length of each side is L+ΔL, where ΔL=αLΔT. Therefore, the new length of each side becomes: $L' = L + \alpha L\Delta T$

3. **Expanded Area:** The new area of the square, A′, after expansion, is: $A' = (L + \alpha L\Delta T)^2$

Expanding this, we get: $A' \approx L^2 + 2\alpha L^2\Delta T$

This simplification is made by neglecting the term $\alpha^2 L^2 (\Delta T)^2$ as it is very small for small temperature changes.

4. **Change in Area:** The change in area ΔA is given by: $\Delta A = A' - A_0$

Substituting A′ and A_0, we find: $\Delta A = (L^2 + 2\alpha L^2\Delta T) - L^2 = 2\alpha L^2\Delta T$

5. **Areal Expansion Coefficient (β):** By definition, the change in area due to temperature is: $\Delta A = \beta A_0 \Delta T$

Substituting $A_0 = L^2$ into this, we get: $\beta L^2\Delta T = 2\alpha L^2\Delta T$

Dividing both sides by $L^2\Delta T$, we find the relationship: $\boxed{\beta = 2\alpha}$

Question (2): Derive relation between coefficient of linear expansion and volume expansion.

To derive the relationship between the linear expansion coefficient (α) and the volumetric expansion coefficient (γ), let's consider a cube made of a material that expands uniformly. The derivation is similar to that of the areal expansion coefficient but extended to three dimensions.

1. **Original Volume:** The original volume of the cube, V_0, is given by $V_0 = L^3$.

2. **Expanded Length:** When heated, each side of the cube expands according to the linear expansion coefficient (α). For a temperature change of ΔT, the new length of each side is L+ΔL, where ΔL=αLΔT. Thus, the new length of each side becomes $L' = L + \alpha L\Delta T$

3. **Expanded Volume:** The new volume of the cube, V′, after expansion, is $V' = (L')^3$. Substituting L′, we get:
   $V' = (L + \alpha L\Delta T)^3$
   Expanding this and simplifying (assuming αΔT is small, so higher order terms can be neglected):
   $V' \approx L^3 + 3\alpha L^3\Delta T$

4. **Change in Volume:** The change in volume ΔV is given by $\Delta V = V' - V_0$. Substituting V_0, we find:
   $\Delta V = (L^3 + 3\alpha L^3\Delta T) - L^3 = 3\alpha L^3\Delta T$.

5. **Volumetric Expansion Coefficient (γ):** By definition, ΔV=γV0ΔT. Substituting$V_0 = L^3$ into this, we get:
   $\gamma L^3\Delta T = 3\alpha L^3\Delta T$

Dividing both sides by $L^3\Delta T$, we find the relationship: $\boxed{\gamma = 3\alpha}$

Question (3): Discuss three units of temperature and write relation between any two.

The three main units of temperature commonly used are:

1. **Celsius (°C)**: Celsius is a widely used unit of temperature in the metric system. It is based on the Celsius scale, where 0°C is the freezing point of water and 100°C is the boiling point of water at standard atmospheric pressure.
2. **Fahrenheit (°F)**: Fahrenheit is a unit of temperature commonly used in the United States and a few other countries. On the Fahrenheit scale, water freezes at 32°F and boils at 212°F at standard atmospheric pressure.
3. **Kelvin (K)**: Kelvin is the base unit of temperature in the International System of Units (SI). The Kelvin scale is based on absolute zero, the theoretical coldest possible temperature, where molecular motion ceases entirely. In the Kelvin scale, 0 K represents absolute zero, and temperatures are measured in relation to this point. The Kelvin scale is used extensively in scientific contexts, especially in physics and chemistry.

General formula for temperature conversion

$$\frac{T_X - T_L}{T_U - T_L} = \frac{T_Y - T_L}{T_U - T_L}$$

Consider two temperature scales X and Y in such that

T_X, T_Y: Any temperatures in scales X and Y

T_L: lower point of temperature

T_U: upper point of temperature

Below is a table showing the upper and lower fixed points (commonly the boiling and freezing points of water) for the three major temperature scales: Celsius, Fahrenheit, and Kelvin.

Temperature Scale	Lower Fixed Point (Freezing Point of Water)	Upper Fixed Point (Boiling Point of Water)
Celsius (°C)	0°C	100°C
Fahrenheit (°F)	32°F	212°F
Kelvin (K)	273.15 K	373.15 K

Question (4): Discuss three practical application of linear thermal expansion.

Everyday examples of thermal expansion:

1. **Metallic Lids on Jars**: When a metallic lid on a jar is difficult to open, heating it can cause the metal to expand, loosening its grip and making it easier to unscrew.
2. **Mercury in Thermometers**: In a thermometer, mercury expands as it is heated and contracts when cooled. This expansion and contraction cause the mercury to rise and fall in the thermometer tube, thereby indicating the temperature.
3. **Balloons in Different Temperatures**: A balloon partially inflated in a cool room will expand when placed in warm water due to the expansion of air inside. Conversely, a fully inflated balloon will shrink when immersed in cold water as the air inside contracts.

Question (5): Define specific heat capacity and write it's SI unit

Specific Heat Capacity:

The amount of heat (in joules) required to raise the temperature of one kilogram of a substance by one degree Celsius (or Kelvin).

Specific heat capacity (or simply specific heat) is a measure of the heat capacity per unit mass of a material. It indicates how much heat energy is required to raise the temperature of unit mass of the material by one degree (Celsius or Kelvin).

- **Formula for Specific Heat Capacity:** The specific heat capacity s is given by:

$$s = \frac{Q}{m\Delta T}$$

where Q is the heat energy added or removed, m is the mass of the material, and ΔT is the change in temperature.

- **Example of Water:** Consider water, which has a high specific heat capacity of approximately 4.18 J/g∘C4.18J/g∘C (or 4186 J/kg∘C4186J/kg∘C). This means that it takes 4.18 joules of energy to raise the temperature of 1 gram of water by 1°C. This property is why water is effective in regulating temperature in nature and in industrial applications.

Question (6): Define molar heat capacity and write it's SI unit

Molar heat capacity is the amount of heat energy required to raise the temperature of one mole of a substance by one degree Celsius (or Kelvin). The formula for molar heat capacity, C, is:

$$C = \frac{Q}{n\Delta T}$$

where:

- Q is the amount of heat added,
- n is the number of moles of the substance,
- ΔT is the change in temperature.

Molar heat capacity is an intrinsic property of a substance, indicating how much heat a substance can store per mole for a given temperature change. It is often reported in units of joules per mole per degree Celsius (J/mol°C) **or joules per mole per Kelvin (J/mol/K).**

Question (7): Define two principle specific heats of gas and discuss which is greater and why.

The two principal molar heat capacities of a gas are:

1. **Molar Specific Heat Capacity at Constant Volume (C_v):** This is the amount of heat required to raise the temperature of one mole of a gas by one degree Celsius while keeping the volume constant. Under constant volume, the gas does not perform work, and all the heat goes into raising the temperature.
2. **Molar Specific Heat Capacity at Constant Pressure (C_p):** This is the amount of heat required to raise the temperature of one mole of a gas by one degree Celsius at constant pressure. Since the gas expands at constant pressure, some of the heat energy goes into doing work against the external pressure in addition to raising the temperature.

The values of C_v and C_p for a gas differ because of the work done during expansion or compression. For an ideal gas, the relationship between them is given by the Mayer's relation:

$$C_P - C_V = R$$

where R is the universal gas constant. The difference arises because, at constant pressure, the gas must do work to expand, which requires extra energy compared to heating at constant volume.

C_p is greater than C_v for gases because heating a gas at constant pressure requires additional energy to perform work of expansion, besides increasing the internal energy of the gas.

Question (8): Define conduction and coefficient of thermal conductivity and write it's SI unit

Conduction:

- Conduction is the transfer of heat through a solid material or between objects in direct physical contact.
- It occurs due to the vibration and movement of atoms and electrons within a substance.
- Heat flows from the hotter part of the material to the cooler part without any movement of the material as a whole.
- Metals typically have high thermal conductivity and are good conductors of heat, due to their free electrons.
- Example: The warmth feeling you get when holding a hot cup of coffee is due to heat conduction from the cup to your hand.

The formula for heat transfer through conduction can be expressed as follows:

$$Q = -kA\frac{\Delta T}{L}$$

Where:

- Q is the heat transfer per unit time (rate of heat transfer), in watts (W).
- k is the thermal conductivity of the material, in watts per meter-kelvin (W/m·K).
- A is the cross-sectional area through which heat is being transferred, in square meters (m^2).
- ΔT is the temperature difference across the material, in kelvins (K) or degrees Celsius (°C).
- L is the thickness of the material (or distance over which the heat transfer occurs), in meters (m).

Coefficient of Thermal Conductivity (k):

- The coefficient of thermal conductivity k is a measure of a material's ability to conduct heat.
- It quantifies the rate at which heat is conducted through a material with a given temperature gradient.
- A higher value of k indicates that the material is a good conductor of heat (like metals), while a lower value means it is a poor conductor or good insulator (like wood or foam).
- The units of thermal conductivity are watts per meter-kelvin (W/m·K), representing the amount of heat that passes through a unit thickness of a material, per unit area per unit temperature gradient.

Question (9): Define convection and discuss the role of convection jn sea breeze and land breeze

Convection is heat transfer through the movement of a fluid due to differences in density. In a sea breeze, during the day, warmer air over land rises, creating low pressure, drawing cooler air from the sea. In a land breeze at night, cooler air over land sinks, creating high pressure, pulling warmer air from the sea. Convection drives these breezes, regulating temperature near coasts.

Question (10): Discuss three important practical applications of thermal conductivity.

1. **Cooking Pots with Copper Coating:**

   - Copper, being a good conductor of heat, has a high thermal conductivity. This property is utilized in cooking pots where a copper coating on the bottom ensures uniform distribution of heat. This leads to more efficient and even cooking, preventing hotspots that can burn food.

2. **Insulation in Buildings:**

   - Materials like plastic foams and glass wool have low thermal conductivity and are used as insulators. These materials contain pockets of air, which is a poor conductor of heat. This characteristic is beneficial in building construction, especially for insulation purposes.

   - In concrete houses, especially those with concrete roofs, the relatively higher thermal conductivity of concrete compared to insulators can lead to significant heat absorption, making interiors hot during summer. To mitigate this, a layer of earth or foam insulation is often added to the ceiling to reduce heat transfer, keeping the rooms cooler.

3. **Thermal Insulation in Clothing:**

   - Clothing materials like wool and certain synthetic fibers have low thermal conductivity, making them excellent for retaining body heat in cold environments.

Question (11): What is principal of calorimetry

Calorimetry involves the measurement of heat exchange within an isolated system where no heat is lost or gained with the surroundings. When two bodies at different temperatures are brought into contact within this isolated system, the heat lost by the hotter body is equal to the heat gained by the colder one. This principle is fundamental in calorimetric measurements and is based on the law of conservation of energy.

Question (12): Discuss Newton's law of cooling

Newton's Law of Cooling describes the rate at which the temperature of an object changes when it is exposed to a surrounding medium with a different temperature. It states that the rate of change of the temperature of an object is directly proportional to the temperature difference between the object and its surroundings.

Mathematically, Newton's Law of Cooling can be expressed as:

$$\frac{dT}{dt} = -k\left(T - T_o\right)$$

Where:

- $\frac{dT}{dt}$ is the rate of change of temperature of the object over time ($^{\circ}Cs^{-1}$).
- T is the temperature of the object at any given time ($\circ C$).
- T_s is the temperature of the surrounding medium ($\circ C$).
- k is the cooling constant, which depends on the properties of the object and the surrounding medium (s^{-1}).

This equation states that the rate of change of temperature $\left(\frac{dT}{dt}\right)$ is proportional to the difference between the temperature of the object and the temperature of its surroundings $\left(T - T_s\right)$. The negative sign indicates that the temperature of the object decreases over time as it cools down to match the temperature of its surroundings.